Nuclear Reaction:-

The reaction in which two nuclei collide to produce different products is called nuclear reaction.

The nuclear reaction $X(a,b)Y$ is written as:-

$$a + X \longrightarrow Y + b$$

The particle a is projectile while X is called target. The particle b is emerging nucleus while Y is called residual nucleus.

Spontenous Reaction

- The reaction in which atomic nuclei splits into two small nuclei without bombarment of external agent.

Non-Spontenous Reaction.

The reaction in which atomic nuclei splits into small nuclei with the help of external agent.

Types of Nuclear Reaction:-

(i) Nuclear Decay:-

The process in which an unstable istope of a particular element spontaneously transform into a new element by emission of ionization radiation is called nuclear Decay.

Sun is natural fusion Reactor and transmutate light element into heavier through process

(ii) Transmutation. (Soddy-1901)

The Conversion of one chemical element into the other atomic nucleus by the bombardment of neutron α, β. There is process called Stellar Nucleosynthesis. This process is proceed in the core of Sun or stars. like the formation of helium, oxygen and carbon in Universe.

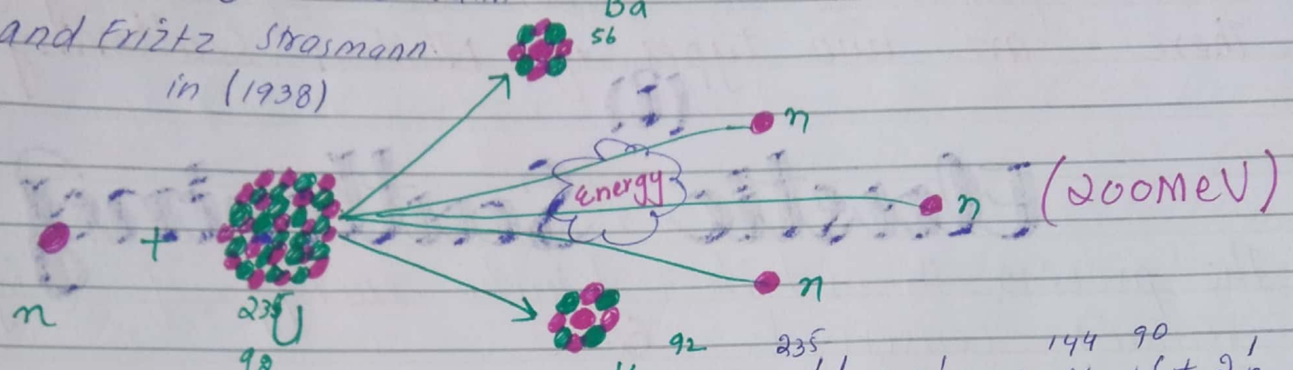
- Examples. α-decay, β-decay, Artificial reaction (particle accelerator)...
- This is reverse process of nuclear decay. It is non-spontenuous process.

(iii) Nuclear Fission Reaction:

- Nuclear Fission is a reaction in which the nucleus of an atom Splits into two or more smaller nuclei and release a very large amount of energy and products are know as Fission products.
- Additional neutrons are released that initiate a chain reaction.
- Fission is a form of Nuclear transmutation because the resulting fragments are not same element as origional atom.
- mass of products < mass of reactants.

- Fission reaction is exothermic Reaction.
- The energy released is used in Electrical experiment and to convert water into steam.

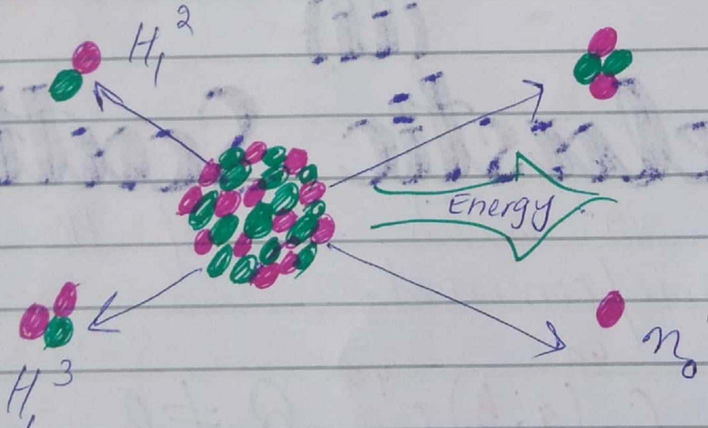
Discovered otto Hann and Fritz Strasmann in (1938)



$^{235}U + n^1_0 \rightarrow {}^{144}Xe + {}^{90}_{40}Sr + 2n^1$

(iv) Fusion Reaction.

The process in which two or more light atomic nuclei fuse or combine to form heavy nucleus is called Fusion Reaction.



Loss of mass that converted into energy during One mole of helium.

$\lambda_{max} \times T = Cons.$

0.018 atm or 1.97×10^9 kg

$\frac{cons}{\lambda_{max}} = T$

Nuclear Scattering:-

Exothermic process:- The process in which energy is transferred to the environment of the system.

There are two types of Nuclear Scattering:-

(i) Elastic Scattering

The process in which Kinetic energy of system remain conserved. $Q=0$

Example:-

$$\frac{1}{2}m_1V_1^2 + \frac{1}{2}m_2V_2^2 = \frac{1}{2}m_1V_1'^2 + \frac{1}{2}m_2V_2'^2$$

- No exchange of nucleons proceed or not provide neucleons or not scattered.

e.g

$$^{208}Pb\,(n,n)\,^{208}Pb$$

(ii) Inelastic Scattering

The process in which K.E of the system does not remain same/conserved.

e.g

$$^{40}C\,(a,b)\,^{40}C \quad Q \neq 0$$

Compton effect.

The neutron is absorbs and then release.

$$a \rightarrow X \rightarrow Y + b$$

Momentum conserved no K.E.

Use:- To slow down nuclear reactions.

Exothermic Nuclear Rect:-

The nuclear Reaction in which energy is released in the environment.

- K.E of products greater than K.E of Reactants.
- Total mass of reactants greater than mass of products.
- The mass is lost in exothermic nuclear Reaction.

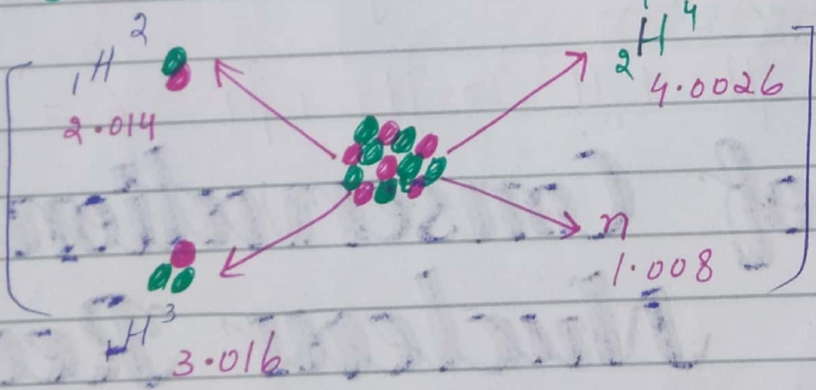
Reason: "The kinetic energy of products increases because binding energy is converted into K.E of Final products".

$Q > 0$

Q Value = Sum of mass of reactant − Sum of mass of products

$E = mc^2 (\quad) \text{ MeV}/c^2$

5.0301 atm



5.0113 atm

$= 5.0301 - 5.0113$

$Q = 0.0188 = m_d$

$E = mc^2$

$= 0.0188 \times 931.48 \text{ MeV}/c^2$

$\boxed{E = 17.5 \text{ MeV}}$

$$_1H^2 + _1H^2 \rightarrow _1H^3 + _1H^1 \quad (4.03\ MeV)$$

$$_1H^2 + _1H^2 \rightarrow _2He^3 + _0n^1 \quad (3.27\ MeV)$$

Endo-Thermic Reaction:

The reaction in which energy does not release into System or Environment.

- To perform or proceed this reaction We must give energy to start reaction.

$$Q < 0$$

- K.E of reactants > kinetic energy of products.
- The initial Kinetic energy is converted into mass or binding Energy.
- Mass is gained.
- mass of products greater than mass of Reactants
- Example:

$$_1H^1 + _1H^3 \rightarrow _1H^2 + _1H^2 \quad Q = -4.03\ MeV$$

Laws of Conservation of Nuclear Reaction:

1. Conservation of charge
2. conservation of mass number
3. Conservation of energy
4. Conservation of linear and Angular Momentum.
5. Conservation of Parity
6. Conservation of isotopic Spin.

(i)

Conservation of Charge.

The total charge on reactant side is equal to total charge on product side in a nuclear reaction is called law of conservation of charge.

$$\Sigma z = \text{Constant}.$$

$$_2He^4 + _7N^{14} \longrightarrow _8O^{17} + H_1^1$$

Reactants $2e + 7e = 9e$

Products $8e + 1e = 9e$

(ii)

Conservation of nucleons:

The total number of nucleons on reactant side is equal to total number of nucleons on product side in nuclear reaction is called conservation of nucleons

$$\Sigma A = \text{constant}$$

$$_2He^4 + _7N^{14} \longrightarrow _8O^{17} + H_1^1$$

Nucleons of reactants $= 4 + 14 = 18$

Nucleons of products $= 17 + 1 = 18$

(iii)

~~The energ~~

Conservation of mass-Energy

The energy of interacting particles in a closed System remains constant is called Law of Conservation of Energy.

This law force to accept the existance of neutrino in beta decay.

Consider a projectile nucleus "a" having kinetic energy "Ea" and mass "ma" is incident on rest target nucleus "X" having mass "mx". The target nucleus X has no kinetic energy because it is at rest.

The product nucleus "Y" generated after nuclear reaction has kinetic energy "Ey" and mass "my". The emerging nucleus "b" generated after nuclear reaction has kinetic energy "Eb" and mass "mb".

The law of mass-energy gives

$$\Sigma(KE + mc^2) = \text{Constant}$$

The nuclear reaction is

$$a + X \longrightarrow Y + b$$

$$(m_a c^2 + E_a) + (m_x c^2 + 0) = (m_y c^2 + E_y) + (m_b c^2 + E_b)$$

$$(m_a + m_x)c^2 - (m_y + m_b)c^2 = E_y + E_b - E_a$$

$$(m_a + m_x)c^2 - (m_y + m_b)c^2 = Q$$

(iv)

Law of Conservation of Linear Momentum:-

The total momentum of a system remains constant in an isolated system is called law of conservation of linear momentum.

$$\Sigma mv = \text{Constant}$$

$$a + X \longrightarrow Y + b$$

$$m_a V_a + 0 \longrightarrow m_y V_y + m_b V_b$$

(iv)

Conservation of angular momentum & Spin:-

Total angular momentum and total spin should be conserved in a nuclear reaction.

$$\Sigma L = \text{constant}$$

Q-Value of Nuclear reaction

Q-Value is defined as:-

The difference between sum of K.E of reactants and sum of K.E of products.

Consider a incident element a having K.E E_a and mass m_a strikes with rest target nucleus X having mass m_x and K.E $E_x = 0$

The product nucleus Y after nuclear reaction having K.E E_y mass m_y and emerging nucleus b having K.E E_b and mass m_b.

Mass-Energy law:-

$$\Sigma(K.E + mc^2) = \text{constant}$$

$$a + X \longrightarrow Y + b$$

$$(E_a, P_a, m_a) \quad (m_x, P=0, E_x=0) \quad (E_y, m_y, P_y) \quad (m_b, P_b, E_b)$$

$$(m_a c^2 + E_a) + (m_x c^2 + 0) = (m_y c^2 + E_y) + (m_b c^2 + E_b)$$

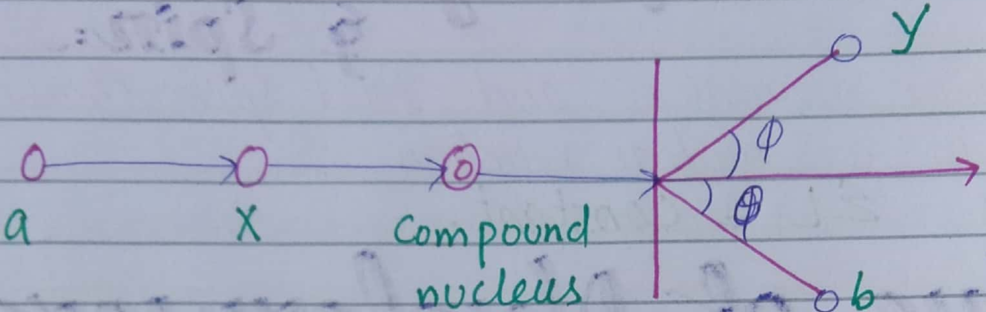
$$m_a c^2 + E_a + m_x c^2 = m_y c^2 + m_b c^2 + E_y + E_b$$

$$m_a c^2 + m_x c^2 - m_y c^2 - m_b c^2 = E_y + E_b - E_a$$

$$(m_a + m_x)c^2 - (m_y + m_b)c^2 = E_y + E_b - E_a$$

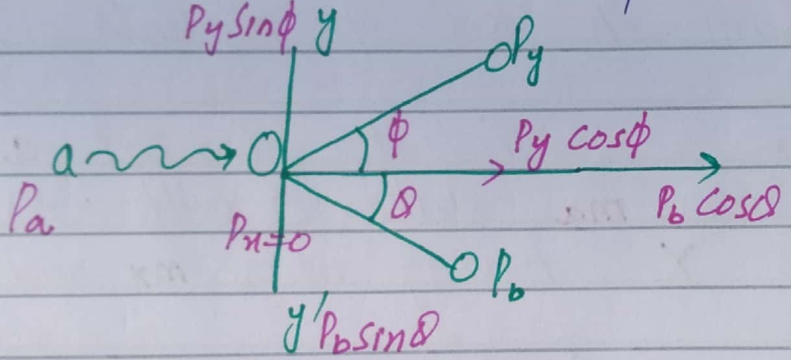
$(m_a + m_x)c^2 - (m_y + m_b)c^2 = Q$

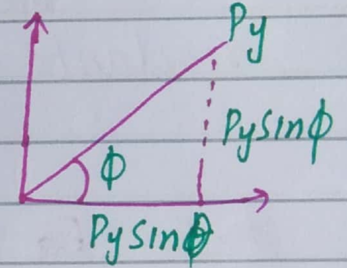
Q Value Equation:- $Q = (E_y + E_b) - E_a \longrightarrow$ (A)

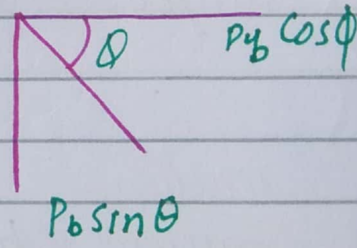


Law of Conservation of momentum:-

Draw momentum into components.







Momentum along X-axis

$P_a + 0 = P_y \cos\phi + P_b \cos\theta$

$P_a = P_y \cos\phi + P_b \cos\theta$

$P_y \cos\phi = (P_a - P_b)\cos\theta \longrightarrow$ (1)

Momentum along Y-axis

$0 = P_y \sin\phi - P_b \sin\theta$ (-y-axis)

$P_y \sin\phi = P_b \sin\theta \longrightarrow$ (2)

Square eq (1) & (2) and add up

$P_y^2 \cos^2\phi + P_y^2 \sin^2\phi = (P_a - P_b\cos\theta)^2 + P_b^2 \sin^2\theta$

$P_y^2(\cos^2\phi + \sin^2\phi) = P_a^2 + P_b^2\cos^2\theta - 2P_aP_b\cos\theta + P_b\sin^2\theta$

$P_y^2 = P_b^2(\cos^2\theta + \sin^2\theta) + P_a^2 - 2P_aP_b\cos\theta$

$P_y^2 = P_b^2 + P_a^2 - 2P_aP_b\cos\theta$

Momentum in terms of Energy:-

$K.E = \frac{1}{2}mv^2$

$E = \frac{1}{2}mv^2 \Rightarrow 2E = mv^2$

$2mE = m^2v^2$

$\sqrt{2mE} = mv \qquad \therefore P^2 = 2mE$

$\sqrt{2mE} = P$

$2m_yE_y = 2m_aE_a + 2m_bE_b - 2\sqrt{4m_aE_am_bE_b}\cos\theta$

$2m_yE_y = 2(m_aE_a + m_bE_b - \sqrt{4m_aE_am_bE_b}\cos\theta)$

$m_yE_y = m_aE_a + m_bE_b - \sqrt{4m_aE_am_bE_b}\cos\theta \rightarrow (3)$

From eq (A)

$E_y + E_b - E = Q$

$\boxed{E_y = Q + E_a - E_b}$

$m_y(Q - E_b + E_a) = m_aE_a + m_bE_b - \sqrt{4m_aE_am_bE_b}\cdot\cos\theta$

$m_yQ - m_yE_b + m_yE_a = m_aE_a + m_bE_b - 2\sqrt{m_aE_am_bE_b}\cos\theta$

$m_yQ = m_yE_b - m_yE_a + m_aE_a + m_bE_b - 2\sqrt{m_aE_am_bE_b}\cos\theta.$

$m_yQ = E_b(m_y + m_b) + E_a(m_a - m_y) - 2\sqrt{m_aE_am_bE_b}\cos\theta.$

$\div$ by (m_y) b.S

$Q = E_b\left(\frac{m_y}{m_y} + \frac{m_b}{m_y}\right) + E_a\left(\frac{m_a}{m_y} - \frac{m_y}{m_y}\right) - \frac{2\sqrt{m_aE_am_bE_b}\cos\theta}{m_y}$

$Q = E_b\left(1 + \frac{m_b}{m_y}\right) + E_a\left(\frac{m_a}{m_y} - 1\right) - \frac{2\sqrt{m_aE_am_bE_b}\cos\theta}{m_y}$

This is called Q-Value equation.

Threshold Energy:-

Minimum possible energy required to start nuclear reaction (endo) is called Threshold energy.

From above eqn of Q-value.

$$E_b\left(1+\frac{m_b}{m_y}\right)+E_a\left(\frac{m_a}{m_y}-1\right)-2\frac{\sqrt{m_aE_am_bE_b}}{m_y}\cos\theta - Q=0$$

$$E_b\left(\frac{m_y+m_b}{m_y}\right)+E_a\left(\frac{m_a-m_y}{m_y}\right)-2\frac{\sqrt{m_aE_am_bE_b}\cos\theta}{m_y}-Q=0$$

$$E_b\left(\frac{m_y+m_b}{m_y}\right)-E_a\left(\frac{m_y-m_a}{m_y}\right)-2\frac{\sqrt{m_aE_am_bE_b}\cos\theta}{m_y}-Q=0$$

$$E_b\left(\frac{m_y+m_b}{\cancel{m_y}}\right)\cancel{m_y}-E_a\left(\frac{m_y-m_a}{\cancel{m_y}}\right)\cancel{m_y}-2\frac{\sqrt{m_aE_am_bE_b}\cos\theta(\cancel{m_y})}{\cancel{m_y}}-Qm_y$$

$$E_b(m_y+m_b)-E_a(m_y-m_a)-2\sqrt{m_aE_am_b}\cos\theta\sqrt{E_b}-Qm_y=$$

Rearranging

$$\underbrace{(m_y+m_b)E_b}_{ax^2}-\underbrace{2\sqrt{m_aE_am_b}\cos\theta\sqrt{E_b}}_{bx}-\underbrace{[(m_y-m_a)E_a+Qm_y]}_{c}=0$$

$$ax^2+bx+c=0$$

$$\sqrt{E_b}=x \Rightarrow E_b=x^2$$

$$a=m_y+m_b$$

$$b=-2\sqrt{m_am_bE_a}\cos\theta$$

$$b^2=4(m_am_bE_a\cos^2\theta)$$

$$c=[(m_y-m_a)E_a+Qm_y]$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\sqrt{E_b} = \frac{2\sqrt{m_a m_b E_a}\cos\theta \pm \sqrt{4 m_a m_b E_a \cos^2\theta + 4(m_y + m_b)(m_y - m_a)E_a + m_y Q}}{2(m_y + m_b)}$$

$$\sqrt{E_b} = \frac{2\left(\sqrt{m_a m_b E_a}\cos\theta \pm \sqrt{m_a m_b E_a \cos^2\theta + (m_y + m_b)(m_y - m_a)E_a + m_y Q}\right)}{2(m_y + m_b)}$$

$$\sqrt{E_b} = \frac{\sqrt{m_a m_b E_a}\cos\theta}{(m_y + m_b)} \pm \sqrt{\frac{m_a m_b E_a \cos^2\theta}{(m_y + m_b)^2} + \frac{(m_y + m_b)(m_y - m_a)E_a + m_y Q}{(m_y + m_b)^2}}$$

$$\sqrt{E_b} = V \pm \sqrt{V^2 + W}$$

$\Rightarrow$ When $\sqrt{E_b}$ is real and (+ive) then there is possibility of nuclear reaction.

$\sqrt{E_b}$ is real when $V^2 + W = 0$

$$\Rightarrow \frac{m_a m_b \cos^2\theta}{(m_y + m_b)^2} + \frac{(m_y - m_a)E_a + Q m_y}{m_y + m_b} = 0$$

By multiplying by $(m_y + m_b)$ on B.S

$$\frac{m_a m_b \cos^2\theta\, E_a}{(m_y + m_b)} + (m_y - m_a)E_a + Q m_y = 0$$

when $\theta \Rightarrow 0$ $\quad E_a \rightarrow E_{ith}$

incident Threshold Energy

$$\frac{m_a m_b (\cos 0)^2 E_{ith}}{m_y + m_b} + (m_y - m_a)E_{ith} + Q m_y = 0$$

By L.C.M

$$\left[\frac{m_a m_b + (m_y + m_b)(m_y - m_a)}{m_y + m_b}\right] E_{ith} = -Q m_y$$

$$\left[\frac{m_a m_b + m_y m_y - m_a m_y + m_b m_y - m_a m_b}{m_y + m_b}\right] E_{ith} = -Q m_y$$

Take m_y common

$$\left(\frac{m_y - m_a + m_b}{m_y + m_b}\right) m_y E_{ith} = -Q m_y$$

$$\left(\frac{m_y - m_a + m_b}{m_y + m_b}\right) E_{ith} = -Q$$

$$E_{ith} = -Q\left(\frac{m_y + m_b}{m_y - m_a + m_b}\right) \rightarrow (3)$$

The Q Value of Reaction:-

$$(m_a + m_x)c^2 - (m_y + m_b)c^2 = Q$$

$$(m_a + m_x) - (m_y + m_b) = \frac{Q}{c^2} \qquad \frac{Q}{c^2} \approx 0$$

$$m_a + m_x - m_y - m_b = 0$$

$$m_x = m_y + m_b - m_a \rightarrow (4)$$

Put (4) in (3)

$$E_{ith} = -Q\left(\frac{m_y + m_b}{m_x}\right)$$

This is Threshold energy.

Transmutation:-

The process in which a atomic nucleus (Unstable) Converted into smaller nuclei (Stable) by bombardment of incident particle with the emission of radioactive rays.

Types:-

① Natural ② Artificial

Natural Transmutation:-

The process in which a heavy nucleus transmulate into stable nuclei/nucleus naturally by emitting α-β-γ particle is called Natural transmutation. (Spontenuous in nature) Their types is:-

(i)

Alpha-Decay

The natural transmutation is called α-Decay when a radioactive element undergoes a nuclear decay through the emission of alpha particle.

$$_{88}Ra^{222} \longrightarrow {}_{2}He^{4} + {}_{86}Rn^{218}$$

(ii)

Beta-Decay

The natural transmutation is called β-decay When a radioactive element Undergoes a nuclear

$_{z}X^{A} \rightarrow Y^{A}_{z+1} + \bar{P}$

decay through the emission of beta particle :-

$_{90}Th^{234} \longrightarrow _{91}Pa^{234} + _{-1}e^{0}$ + antineutrino

(iii)

Gamma-Decay

- Gamma rays are high-energy electromagnetic radiations.
- they are generally emitted as secondary effect of alpha or beta-decay.
- The nuclei reached in its excited state because of alpha decay or β-decay
- Hence excess of energy is released in the form of Gamma-rays.
- The γ-rays are neutral in nature with negligible mass.
- No change in mass number and atomic number of daughter nuclei compare to parent nuclei.

$Co^{60} \rightarrow Co^{*60} + \gamma$

Scanned with CamScanner

Transmutation by deutron

History:-

Deutrium / Deutrons was discovered by Harled Urey (1931). (1933 N.P) It is derived from Greek word deutron and (second).

Introduction / Characteristics:-

1. Deutron is an isotope of Hydrogen atom having atomic mass 2.
2. It present in natural hydrogen with relative abundance of (0.015%).
3. It can be obtained by electrolysis of water (D_2O)

Reactions:-

With the help of particle accelerates deutrons can be accelerated to high energy and can be used as projectiles to induce various types of nuclear reactions by emitting α, β and neutron, Minimum 2MeV energy is sufficient to produce reaction.

General form of Deutron Reaction:-

$$_1H^2 + X \longrightarrow {}_{Z+1}C_n^{A+2}$$

Mechanism:-

$$ {}_{Z+1}Cn^{A+2} \rightarrow Y^{A+1}_{Z+1} + {}_0n^1 $$

$$ {}_{Z+1}Cn^{A+2} \rightarrow Y^{A+1}_{Z} + P({}_1H^1) $$

$$ {}_{Z+1}Cn^{A+2} \rightarrow Y^{A-2}_{Z-1} + {}_2H^4 $$

Theoretical explanation of Mech...

- Target nucleus split into proton and deutron by the help of coulomb force.

$$ d \rightarrow X \rightarrow P + n $$

- When deutron ${}_1H^2$ collide with nucleus there are possibilities that either neutron enter into target nucleus or proton enter into target nucleus.

- But neutron enter 1st into target nucleus because it has no charge and no repulsion and attract by coulomb force.

$$ n_0^1 + {}_ZX^A \longrightarrow {}_ZCn^{A+1} + P $$

$$ P + {}_ZX^A \longrightarrow {}_{Z+1}Cn^{A+1} + n $$

- Deutron Reactions are exothermic.

1. (d,α)

By pair deutron induced to target nucleus and produce α-particals

$${}_{1}H^{1} + {}_{3}Li^{7} \rightarrow {}_{4}[Be]^{8} \rightarrow 2He^{4} + {}_{2}H^{4}$$

$${}_{1}H^{1} + {}_{z}X^{A} \rightarrow [Cn_{z+1}^{A+2}] \rightarrow Y_{z-1}^{A-2} + {}_{2}He^{4}$$

2. (D,P)

By Pair (d,P) deutron collide with nucleus and produces Proton → increas in mass.

$${}_{1}H^{2} + {}_{z}X^{A} \rightarrow [{}_{z+1}Cn^{A+1}] \rightarrow {}_{z}X^{A+1} + {}_{1}H^{1}$$

$${}_{1}H^{2} + {}_{6}C^{12} \rightarrow [{}_{7}N^{14}] \rightarrow {}_{6}C^{13} + {}_{1}H^{1}$$

3. (d,n)

When deutron strikes with nucleus it produces neutron (n^{1})

$${}_{1}H^{2} + {}_{z}X^{A} \rightarrow [{}_{z+1}Cn^{A+2}] \rightarrow {}_{z+1}Y^{A+1} + {}_{0}n^{1}$$

$${}_{1}H^{2} + {}_{6}C^{12} \rightarrow [{}_{7}N^{14}] \rightarrow {}_{7}N^{13} + {}_{0}n^{1}$$

4. (d,T)

By pair deutron induced on nucleus and produces Tritum (T).

$${}_{1}H^{2} + {}_{z}X^{A} \rightarrow [Cn_{z+1}^{A+2}] \rightarrow {}_{z}X^{A-1} + {}_{1}H^{3}$$

$${}_{1}H^{2} + {}_{3}Li^{7} \rightarrow [{}_{4}Be^{9}] \rightarrow {}_{3}Li^{6} + {}_{1}H^{3}$$

Transmutation by α-particles:-

History:-

(α^{2+}, H^{2+}, ${}_2He^4$)

- In 1907 Earnst Rutherford and Thomas Royds proved that alpha particles were helium ions.
- In 1927 Rutherford use alpha partical and accidentally proceed a direct nuclear Transmutation of one element to another.
- 1919, First, discovery of Transmutation by α-particles are given as.

$${}_7^{14}N + \alpha \longrightarrow {}_8^{17}O + P$$

Production:-

Naturally:- produce by decay of Uranium + Thorium, Radium - Radon.

Artificially:- Particle Accelerator (cyclotrons, Synchrotons.

Reactions:-

The transmutation by α-particle cause to change in atomic mass and atomic number. and can be proceed at 5MeV.

Possible nuclear Reaction

[(α, P), (α, n) & (α, γ)]

i) (α, P)

General form of α, P reaction is:

$${}_2He^4 + {}_ZX^A \longrightarrow {}_{Z+2}Cn^{A+4} \longrightarrow {}_{Z+1}Y^{n+3} + {}_1H^1$$

E.g

$${}_2H^4 + {}_5B^{10} \longrightarrow [{}_7N^{14}] \longrightarrow {}_6C^{13} + {}_1H^1 + 4.04\,MeV$$ BNC

$${}_2H^4 + {}_{14}Si^{28} \longrightarrow {}_{15}P^{31} + {}_1H^1 \quad -1.92\,MeV$$ SiP

Note:– The reactions are Endoergic for medium heavy nuclei and Exoergic for lighter nuclei (maybe)

ii) (α, n)

General form of (α, n) Reaction is:–

$${}_2He^4 + {}_ZX^A \longrightarrow [{}_{Z+2}Cn^{A+4}] \longrightarrow {}_{Z+2}Y^{A+3} + {}_0n^1$$

e.g

$${}_2He^4 + {}_7N^{14} \longrightarrow [{}_9F^{18}] \longrightarrow {}_9F^{17} + {}_0n^1$$ NFF

$${}_2He^4 + {}_4Be^9 \longrightarrow [{}_6C^{13}] \longrightarrow {}_6C^{12} + {}_0n^1 \quad +5.7\,MeV$$ BeCC

$${}_2He^4 + {}_3Li^7 \longrightarrow {}_5B^{10} + {}_0n^1 \quad -2.79\,MeV$$ LiB

$${}_2H^4 + {}_8O^{18} \longrightarrow {}_{10}Ne^{21} + {}_0n^1 \quad -0.7\,MeV$$ ON

$${}_5B^{11} + {}_2He^4 \longrightarrow {}_7N^{14} + {}_0n^1 \quad +0.15\,MeV$$ Hen.

iii) (α, γ)

$${}_2H^4 + {}_3Li^7 \longrightarrow {}_5Be^{11} \longrightarrow {}_5B^{11} + \gamma$$

Compound nucleus:-

It is formed by the bombardment of incident nuclei on heavy nucleus.

$a + X \longrightarrow [a+X]^*$

1. Projectile nuclei totally absorb in heavy nucleus. (10^{-15} to 10^{-19}) s
2. After spending some life time → Split into residual nuclei and emerging nuclei.

Products dependence.

Product nuclei depend upon Energy, mass, angular momentum of compound nucleus.

Limitations:-

Nucleus Theory (Bohr', 1937)

(1)

In some cases decay of compound nucleus into products is not independent of entrance channel as angular momentum, Energy distribution of emitted particle is consistent with incident particle and target nucleus.

(2)

Compound nucleus theory does not explain the mechanism by which excitation energy is randomly shared by/to all nucleons by target nucleus and eventually emitted / concentrated by one nuclei.

(3)

It does not tell about the cross section of formation of compound nucleus with incident K.E.

(4)

It does not explain the mechanism of direct nucleus reaction indicated by the lighter nuclei.

(5)

According to compound nucleus theory compound nucleus should loses some energy although it is formed by different entrance channel.

(6)

Incident projectile loses its identity when make collision with large target nucleus this not true for lighter nuclei.

Nuclear Cross Section:-

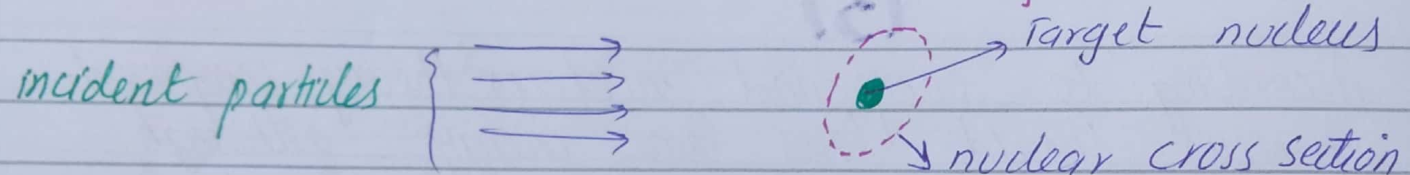
The nuclear cross section (or intracting cross section) is that area around the nucleus facing the incident particles, within which the incident particle will lead to an intraction with nucleus.

denoted by σ

It is expressed in Unit area.

$1 \text{ barn} \approx 10^{-24} cm^2 \approx 10^{-28} m^2$

$= 100 fm^2$



$\sigma = \pi R^2$

Dependence of N-Cross Section:-

- Nature of incident particles.
  Protons, Neutrons and electrons
- Area of cross section is very low in case of Proton.
- For Neutron area of cross section is greater than proton. (velocity high then neutron, n° less intract).

$E \propto \frac{1}{6}$

~ 50MeV electron moderate

Energy:-

As we seen for case of neutron if velocity high de-Broglei λ is small so intraction area small.

but if velocity low then neutron fully (Probabily) intract with nucleus.

Explanation:-

Consider a particle passing through a thin sheet (slab, sheet) of target material having area A. If the number of Target nuclei is N then the probility of particle to intract with nucleus is given as:

Probability of collision = $\frac{\text{amount of area avaible for enter}}{\text{Total area facing Particles}}$

$= \frac{N_T \sigma}{A}$

where σ is cross section.

$\frac{N_T}{A}$ = Surface density $\rightarrow$ (1)

as sheet has Area A and thickness (t).

$= \frac{N_T}{A} \times \frac{t}{t}$ $V = L \times W \times L$

$= \frac{N_T}{V} \times t$

$= N \times t \rightarrow$ (2)

$\frac{N_T}{V}$ = Surface density.

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Compare eq 1 & 2

$$\frac{N_T}{A} = N \times t \rightarrow (3)$$

let consider n. no of particles intract per unit volume and moving with velocity V

No. of particles crossing unit area per unit time is called flux.

$$\text{Particle flux} = \frac{\text{Particle}}{\text{Area} \times \text{time}}$$

$$= \frac{\text{Particle} \times V}{\text{Area} \times \text{distance}}$$

width, dx, x.

$$= \frac{\text{Particle} \times V}{A \times x \text{ or } dx}$$

$$= \frac{nV}{\text{Volume}}$$

$$P.F = nV$$

$$\frac{\text{Particle}}{\text{Area} \times \text{time}} = nV$$

$$\frac{\text{collision} \times \text{Particle}}{\text{Area} \times \text{time}} = nV \times \text{collision}$$

$$= nV \times \frac{N_T \sigma}{A}$$

$$\frac{\text{no}}{\text{Area} \times \text{time}} = NV\sigma N_t$$

$$\frac{\text{no}/\text{Area}/\text{time}}{nVN_t} = \sigma$$

liquid drop Model:-

Introduction:- There are many model purposed at different time. but liquid drop model is very important in nuclear physics.

Historical Background:-

The model was purposed by Bohr, Whealer in 1937 and also by Frenkel independently. They called nucleus as Homogenous entity consist of certain number of Protons and neutrons.

Similarities:-

(1)

As drop of liquid is consist of large number of molecules which are present in same volume. Similarly nucleus is made up of large number of protons and neutrons present in the same nuclear volume.

(2)

The drop of liquid is homogenuous in density like volume etc, also density of nuclus is same.

(3)

As drop of liquid cannot be compressed Similarly nucleus cannot be compress.

(4)

In the case of liquid drop the forces between all the molecules are the same. Similarly

nuclear forces in all the nucleons are same.

$$f(P-P) \approx f(P-n) \approx f(n-n)$$

(5)

When a very small amount of liquid is added to the drop the liquid drop grows in size this is called nuclear fusion reaction.

e.g. $_7N^{14} + {_2He^4} \longrightarrow {_9F^{18}}$

$$O + O \longrightarrow \infty$$

Similarly when incident particles are projectile can be added to nucleus forming the compound nucleus.

(6)

A very big drop of liquid breaks up into smaller droplets Similarly heavy nucleus breaks up into smaller nuclei (nuclear fission reaction).

e.g. $_{92}^{235}U + {_0n^1} \longrightarrow {_{56}^{144}Ba} + {_{36}^{89}Kr} + 3({_0n^1}) + \text{Energy}$

(7)

In liquid drop evaporation take place Similarly in nuclear reaction emission of nucleons takes place. This is example of transmutation reaction.

Advantages:-

- It explain the phenomena of Nuclear Fission.
- It explain the phenomena of Nuclear Fussion.
- It helps to find binding energy of nuclei.
- It pridicts the emission of α, β and γ-rays.
- It support the theory of Bohr's theory of compound nucleus.

Semi-Emperical Formula:-

(mass Formula)

Introduction:-

The Semi-Emperical Formula was proposed by Bethe-Weizsacker in 1935 called mass Formula. This formula is used to approximate the mass and various other properties of atomic nucleus from its number of protons and neutrons.

Dependence:-

- Partially based on Theory
- Partially based on Emperical Measurements.

Explanation:-

(Theory Base) We know that total mass of nucleus comes out from mass of protons and neutrons. (Measurements) But in reality there are some approximations and assumptions that actual mass of nucleus is less than to the seperately addition mass of protons and neutrons.

Mathematically:-

As we know that
Actual mass Nucleus < (mass P + mass N)
So, there is an Mass defect / deficite.
Some part of mass changes into E_B.
Let us consider Nucleus X_Z^A the

$A = (m_p + m_n)$

$A = Z + N$

$\boxed{A - Z = N}$

Mass deficite:-

Δm or $\Delta M = Zm_p + (A-Z)m_n) - M$

So Binding Energy

E_B or $B \cdot E = \Delta m c^2$

$E_B = (Z(m_p) + (A-Z)m_n - M)c^2$

$\frac{E_B}{c^2} = (Z(m_p + (A-Z)m_n - M)$

$\boxed{{}_ZX^A = M = [Z(m_p) + (A-Z)m_n - E_B/c^2]}$

Binding Energies based on 5 Energies:-

Binding Energy
- → Volume Energy E_v
- → Surface Energy E_s
- → coloumb Energy E_c
- → Asymmetry Energy E_t
- → Pairing Energy E_p or E_δ.

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Volume Energy:-

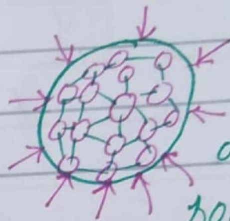
The Volume of nucleus/sphere proportion of nuclear.

$$A \propto \frac{4}{3}\pi R^3$$

$$A \propto R^3$$

$$\Rightarrow R \propto A^{1/3} \Rightarrow R = R_0 A^{1/3}$$

⇒ Increas the Volume cause to increase the Radius of constant. We also know that volume is directly linked with No. of nucleons.



$$V \propto A$$

$$E_V \propto A$$

$$E_V = a_V A$$

a_V is constant having value 15·5 MeV

⇒ This formula also shows that nucleons tightly/strongly attached by their neighbouring.

Surface Energy:-

The Surface energy is decreases because the nucleon present at the surface have less attractive forces with neighbouring nucleons. But strong force inside volume/nucleons.

$$E_B = E_S \propto \text{No. of Nucleons at Surface}$$

$$E_S \propto A \text{ (Surface Area)}$$

$R = R_0 A^{1/3}$

$$E_S \propto 4\pi R^2$$

$$E_S \propto 4\pi (R_0 A^{1/3})^2$$

$$\boxed{E_S = -a_S A^{2/3}}$$

a_S Constant having having Value -16·8 or 18·34 MeV.

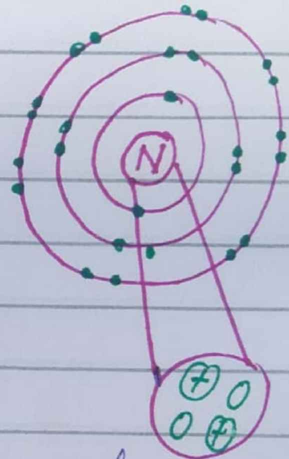
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Nuclear Shell Model:-

Introduction:-

Nuclear Shell Model is a model of atomic nucleus which uses to describe the structure of nucleus in terms of energy levels. These energy levels are called Binding energy levels.

Historical Background:-



It is 1st time introduced by Dmitry, E. Grapon 1932. The most noteable model was proposed by Paul weigner and Maria Mayer and J. Hans 1949.

Explanation:-

According to this atomic model of element. There are some sort of electrons in shell e.g (K=2) (L=8) (M=18), (N=32). To remove the electron from orbit of the atom we required energy in eV to remove the electron from atom having stable orbit. Similarly in the case of nucleus we required energy in MeV to remove proton or neutron from stable nucleus.

Magic numbers:-

The magic numbers are nucleons due to which nucleus shows most stability called magic numbers.

For Protons:- 2, 8, 20, 28, 50, 82, 144.

For Neutrons:- 2, 8, 20, 28, 50, 82, 144, 126, 184.

e.g $_{2}He^{4}$

Double Magic numbers:-

If the no of protons and neutrons both are equal to given magic numbers then it is called double magic number.

e.g $_{20}Ca^{40}$, $_{8}O^{16}$, $_{2}He^{4}$

They are also called extra-stable nuclei.

So nucleus which have number of nucleons equal to these magic number is called as more-stable nucleus.

Significance:-

(1)

The nuclei having protons or neutrons as magic number have greater no of isotopes than other nuclei.

e.g $_{50}Sn^{118}$

(2)

Nucleus having protons no and neutrons no is equal to magic number are more stable/show extra stability.

(3)

Successfully explain the nuclear properties of the nucleus.

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It is also used to describe the bonding energy of the nucleons and also explain the relative abundance of nucleons.

Bohr and Whealer theory of nuclear fission:-

Introduction:-

Bohr and Whealer in 1939 develop the theory of nuclear fission on the basis of liquid drop model of the nucleus.

- The nucleus is considered as charge liquid drop which is deform by the application of external force.

The force is provided by the incident neutrons. The neutron combines with target nucleus to form a compound nucleus which is highly energetic.

- The total energy given to the compound nucleus is sum of

K.E of neutron + neutron B.E in CN.

- If the total energy is equal to the threshold energy then fission reaction takes place.

The process can be represented by diagram.